LA-UR-02-6522

Title: QAM Multi-path Characterization Due to Ocean Scattering

Author(s): Thomas L. Petersen, ESA-WR
Roger R. Bracht, ESA-WR
Regina V. Pasquale, ESA-WR
Jeffery Dimsdle, Honeywell
Richard Swanson, Honeywell

Submitted to: International Telemetering Conference
San Diego, CA
October 21-24, 2002

LOS ALAMOS NATIONAL LABORATORY

3 9338 01045 9690

Los Alamos
NATIONAL LABORATORY

Form 836 (8/00)

QAM Multi-path Characterization Due to Ocean Scattering

Richard Swanson, Jeff Dimsdle
Honeywell/ASMF&T

Tom Petersen, Regina Pasquale, Roger Bracht
Los Alamos National Laboratory

Abstract

A series of RF channel flight characterization tests are to be run, in early March, to benchmark high speed, 16QAM multi-path performance over the ocean surface. The modulation format being tested is a 16 differential phase, absolute amplitude, two level polar quadrature amplitude modulation. The bit rate is 100 Megabits per second. This transmitted signal will be generated in a burst mode, being on for 40 microseconds once every 40 milliseconds. An aircraft will radiate the RF test signal at 5 different altitudes. The aircraft will make two inward flights at each altitude with vertical and horizontal polarization respectively. Receivers are to be placed in two different locations using circular antenna polarization. One receiver will be placed at an altitude of 230 feet above the ocean surface, and the other on a boat with the antenna placed just up off of the ocean surface. Data is to be collected over multiple wavelength changes in the difference between the line of sight and the reflected multi-path ray. The real time signal strength variation is to be recorded as well. Analysis of the resulting data will show flat fading and frequency selective fading effects. The test is run over two different days to provide for some variation in sea state conditions. This resulting information will help quantify the effectiveness of this novel modulation scheme for missile telemetry end event data applications.

QAM Multi-path Characterization Due to Ocean Scattering

Presented by:

Roger Bracht

Authors:

Richard Swanson, Jeff Dimsdle
Honeywell Federal Manufacturing & Technologies

Tom Petersen, Regina Pasquale, Roger Bracht
Los Alamos National laboratory

Presentation to ITC 2002
San Diego, CA
October 22, 2002

Honeywell

Los Alamos

Aircraft Test Description

Transmitted from aircraft at 5 altitudes

Horizontal and Vertical polarizations

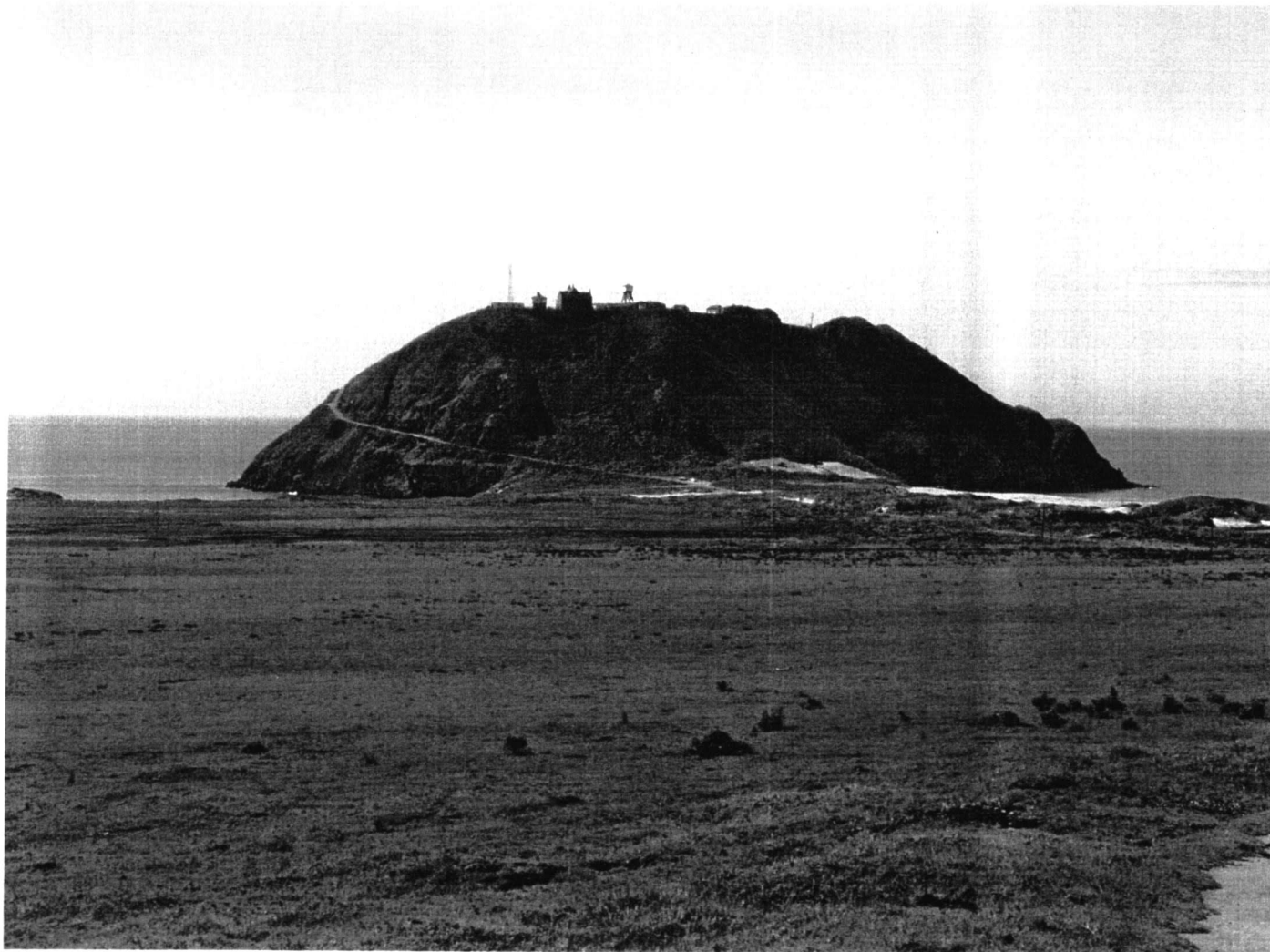One receiver at Point Sur Lighthouse 230' above sea level

Other receiver on a boat with antenna just above the ocean surface

Two separate test days: Tuesday very calm seas, Friday fairly rough seas
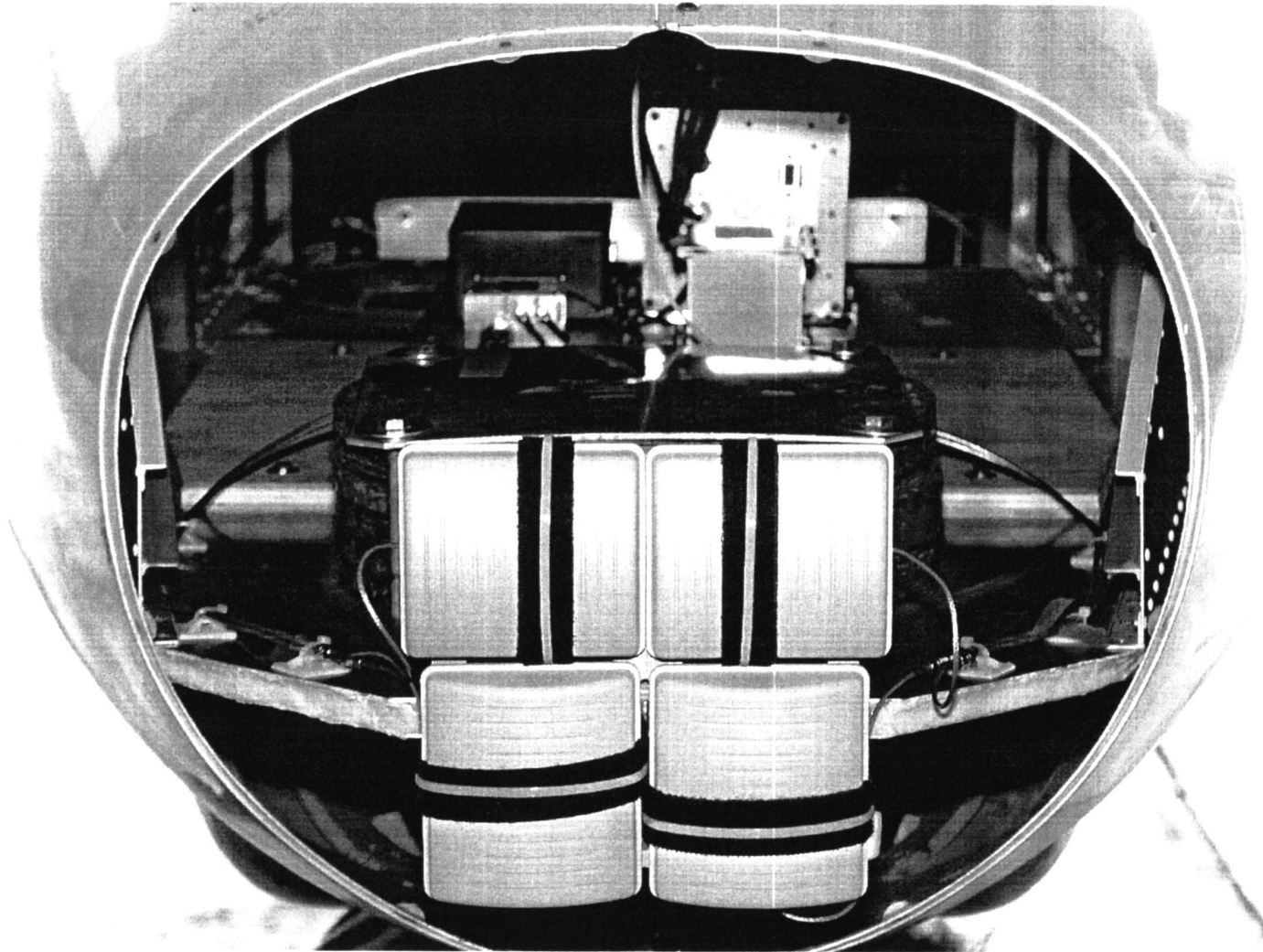
Honeywell

Los Alamos

Pt. Sur

Los Alamos

Pelican Aircraft

Los Alamos

FQPSK, HERT, and Antennas
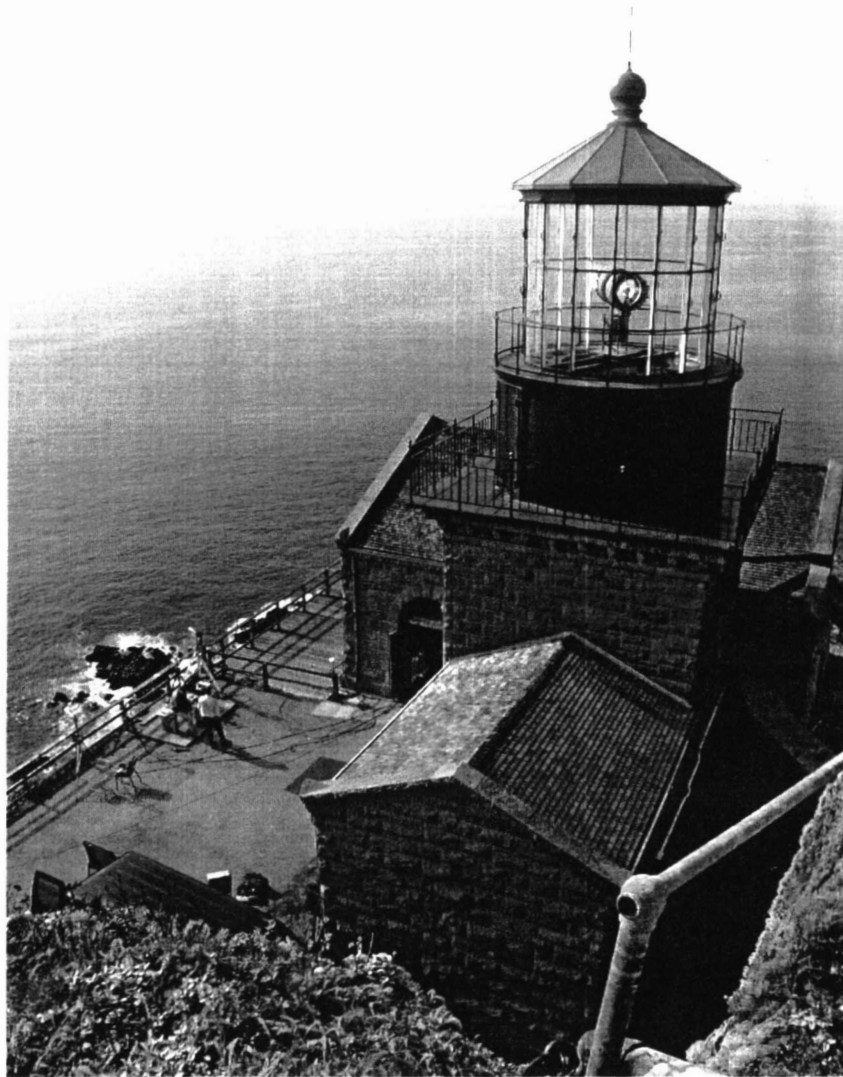
Pt. Sur Light House

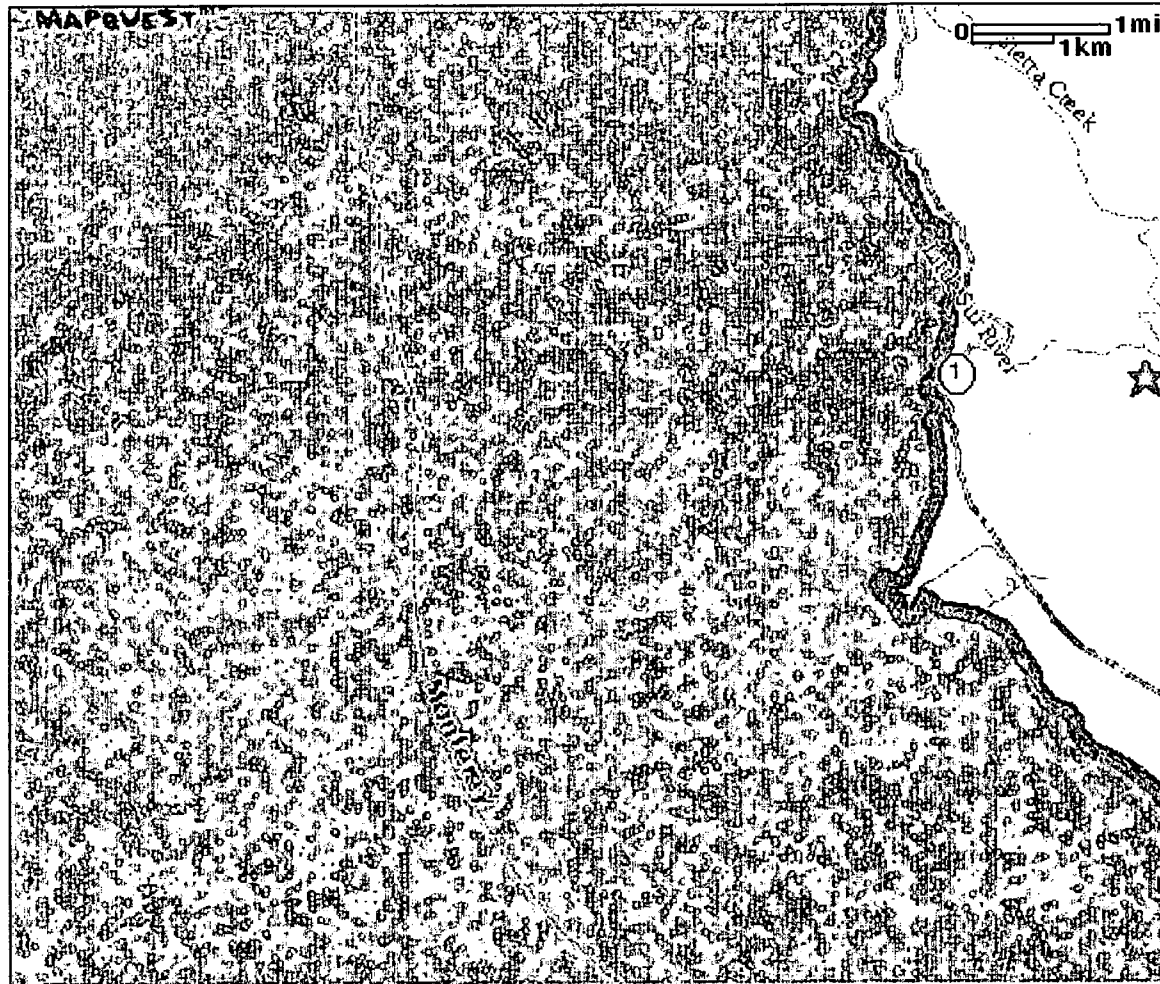Los Alamos

Antenna Farm

Honeywell

Los Alamos

Buoy Simulator

Testing

Honeywell

Los Alamos

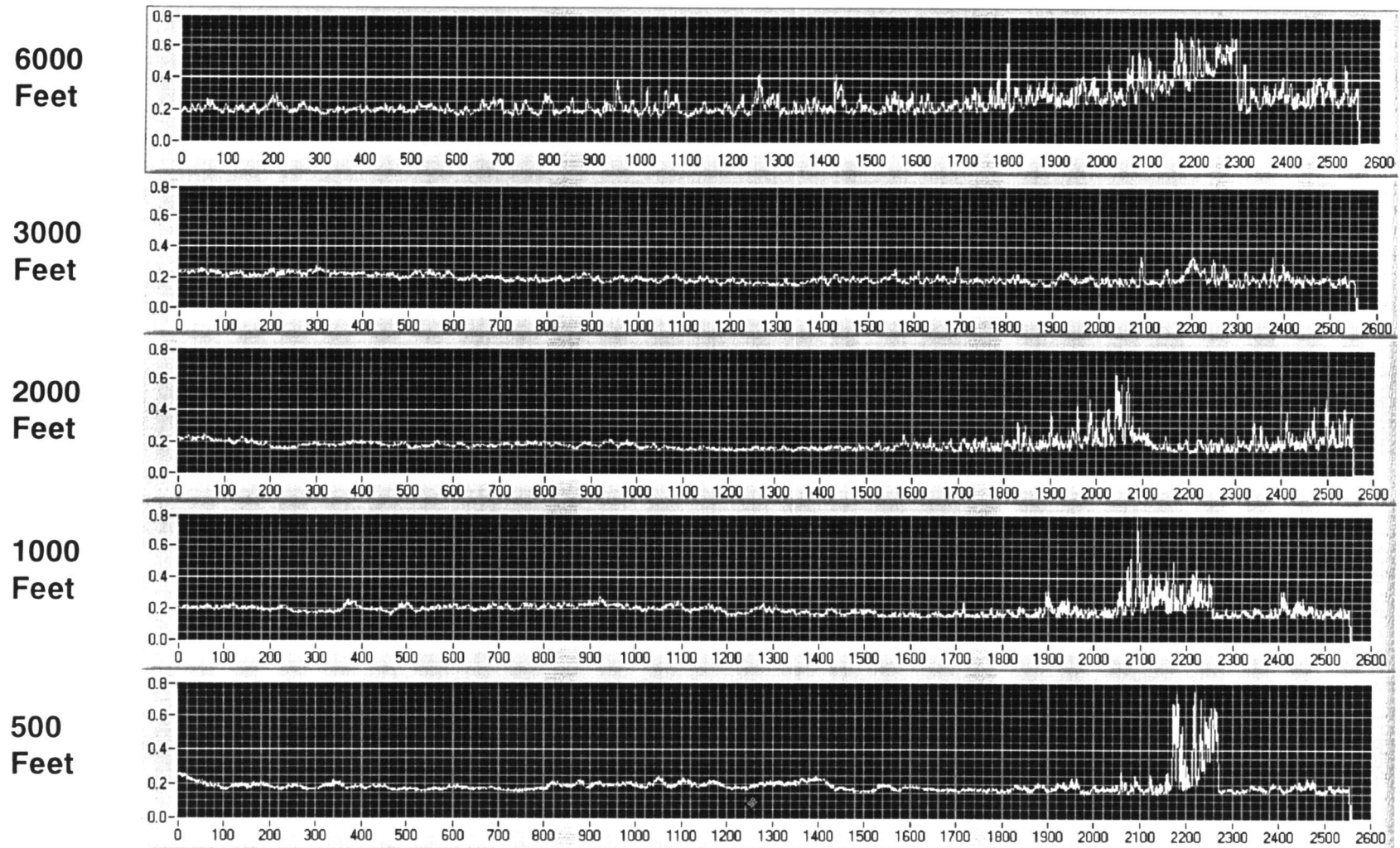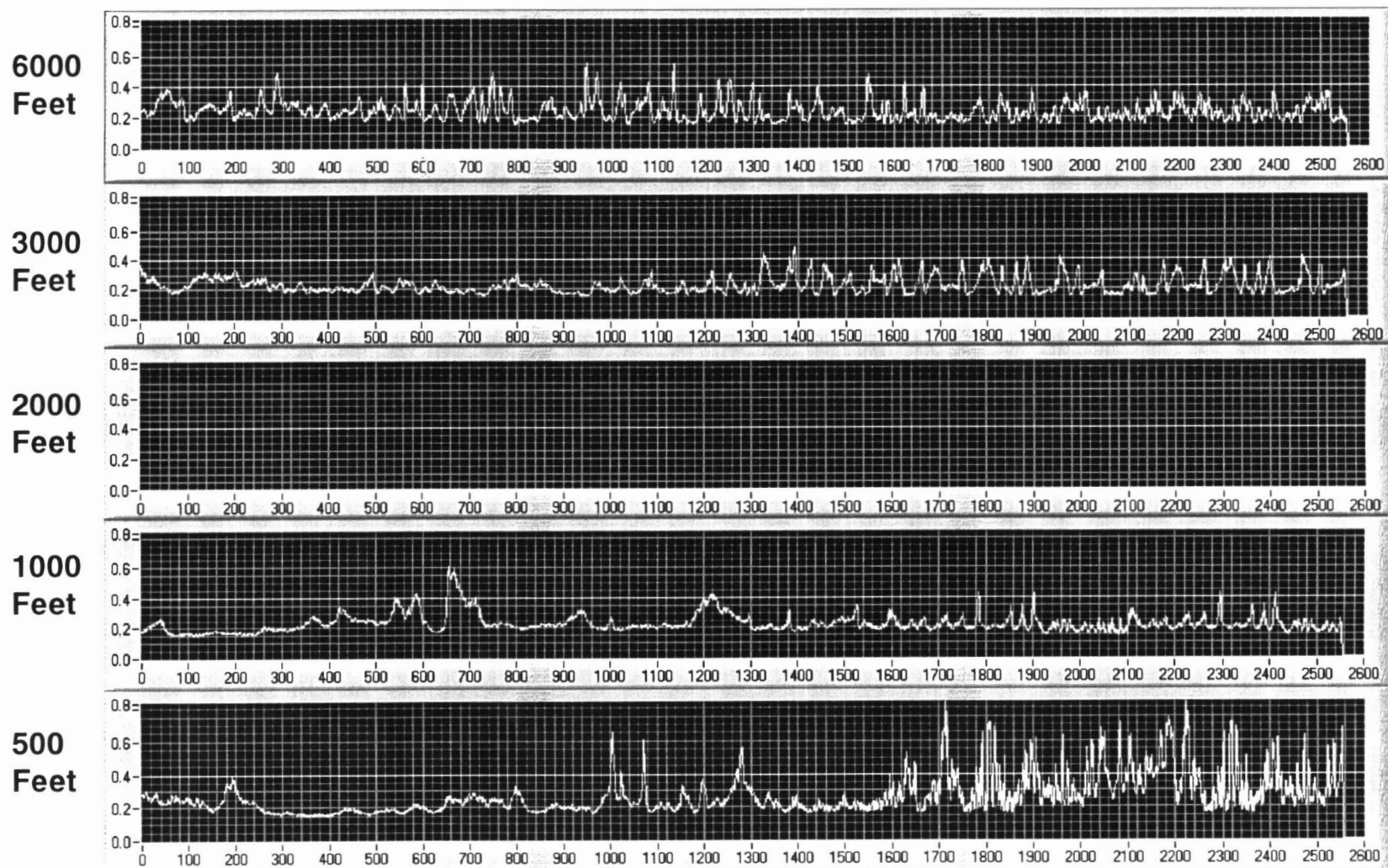# Pt. Sur

Los Alamos

Calm Water Airplane to Boat with Vertical Radiator - QAM Deviation Spreads

Calm Water Airplane to Boat with Horizontal Radiator - QAM Deviation Spreads

6000 Feet

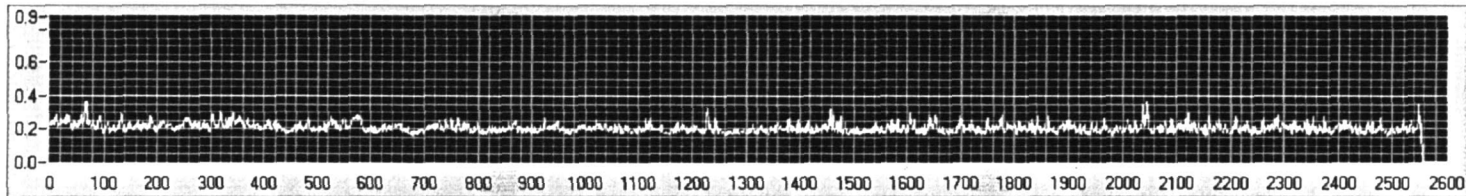**3000 Feet**

2000 Feet

1000 Feet

500 Feet

Honeywell

Los Alamos

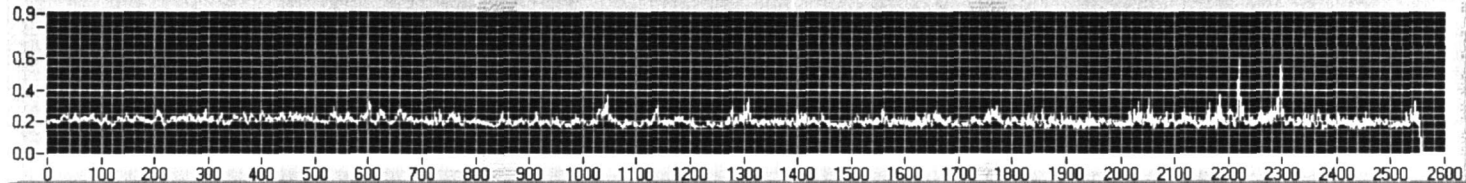# Rough Water Airplane to Boat with Vertical Radiator - QAM Deviation Spreads

6000 Feet

3000 Feet

2000 Feet

1000 Feet

500 Feet

Honeywell

Los Alamos

Rough Water Airplane to Boat with Horizontal Radiator - QAM Deviation Spreads

Honeywell
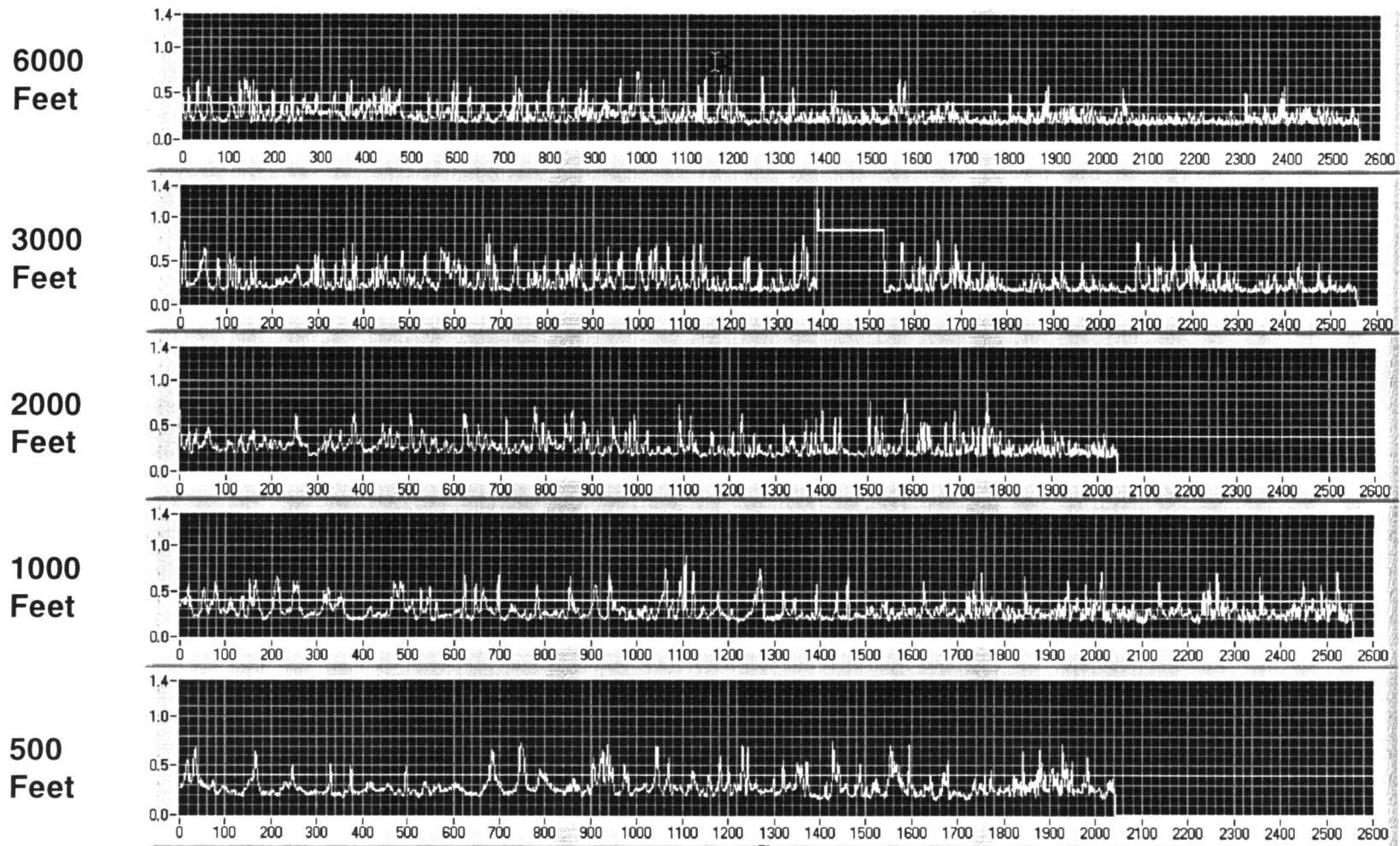
Los Alamos

Constellation Before Equalization

Honeywell
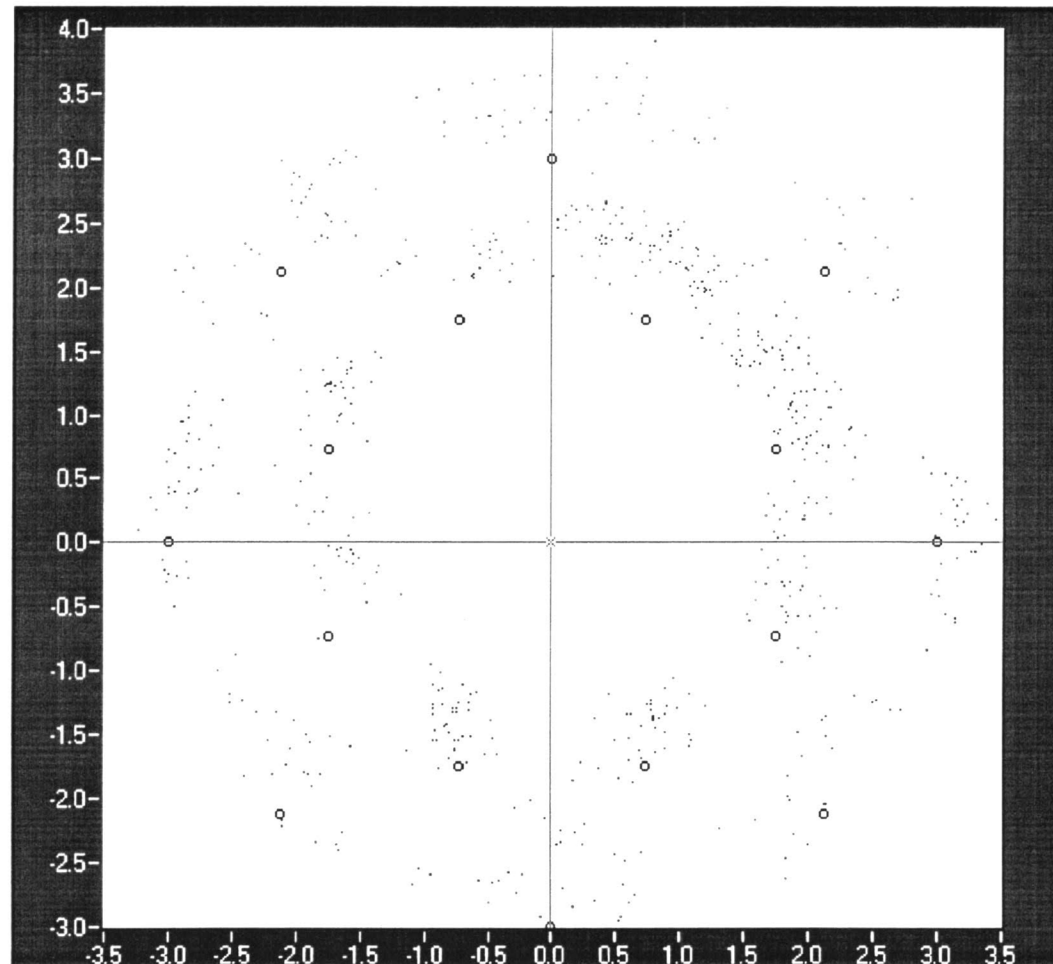
Los Alamos

Constellation After Equalization
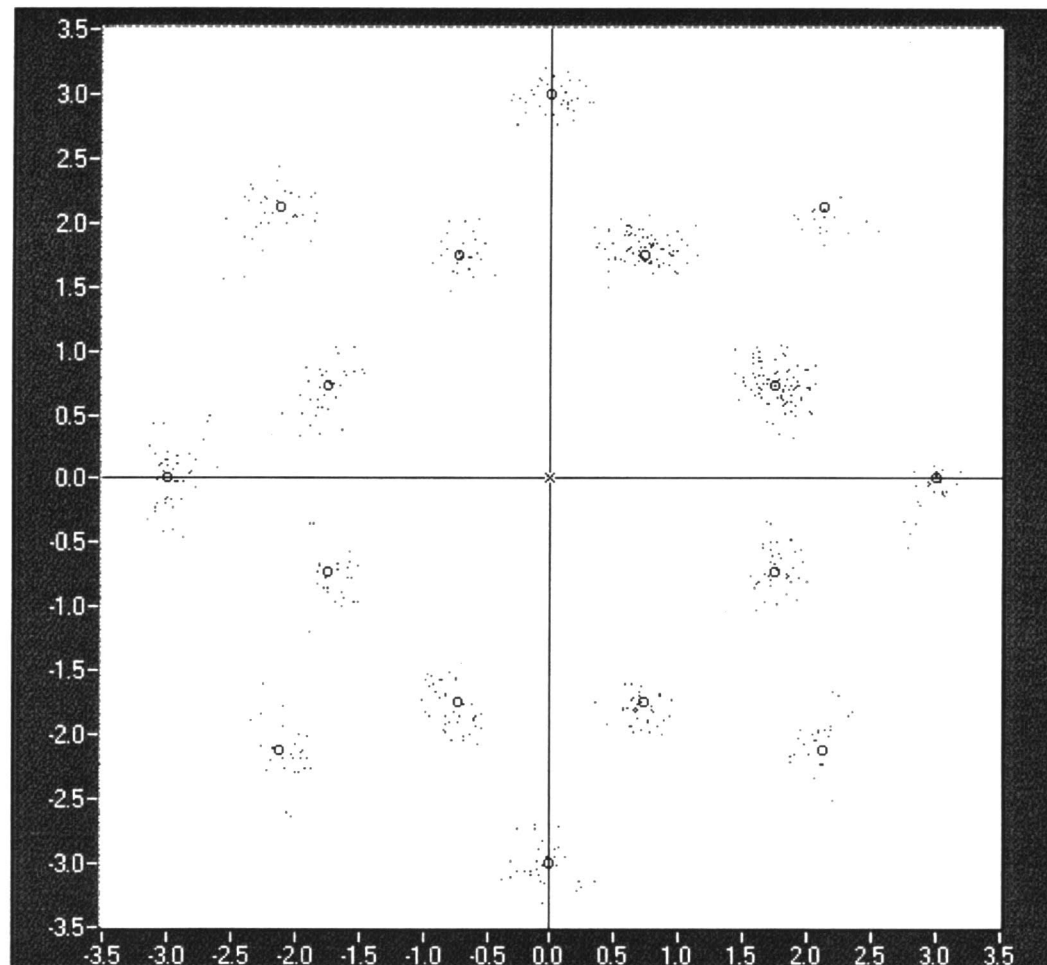
Spectrum Before Equalization
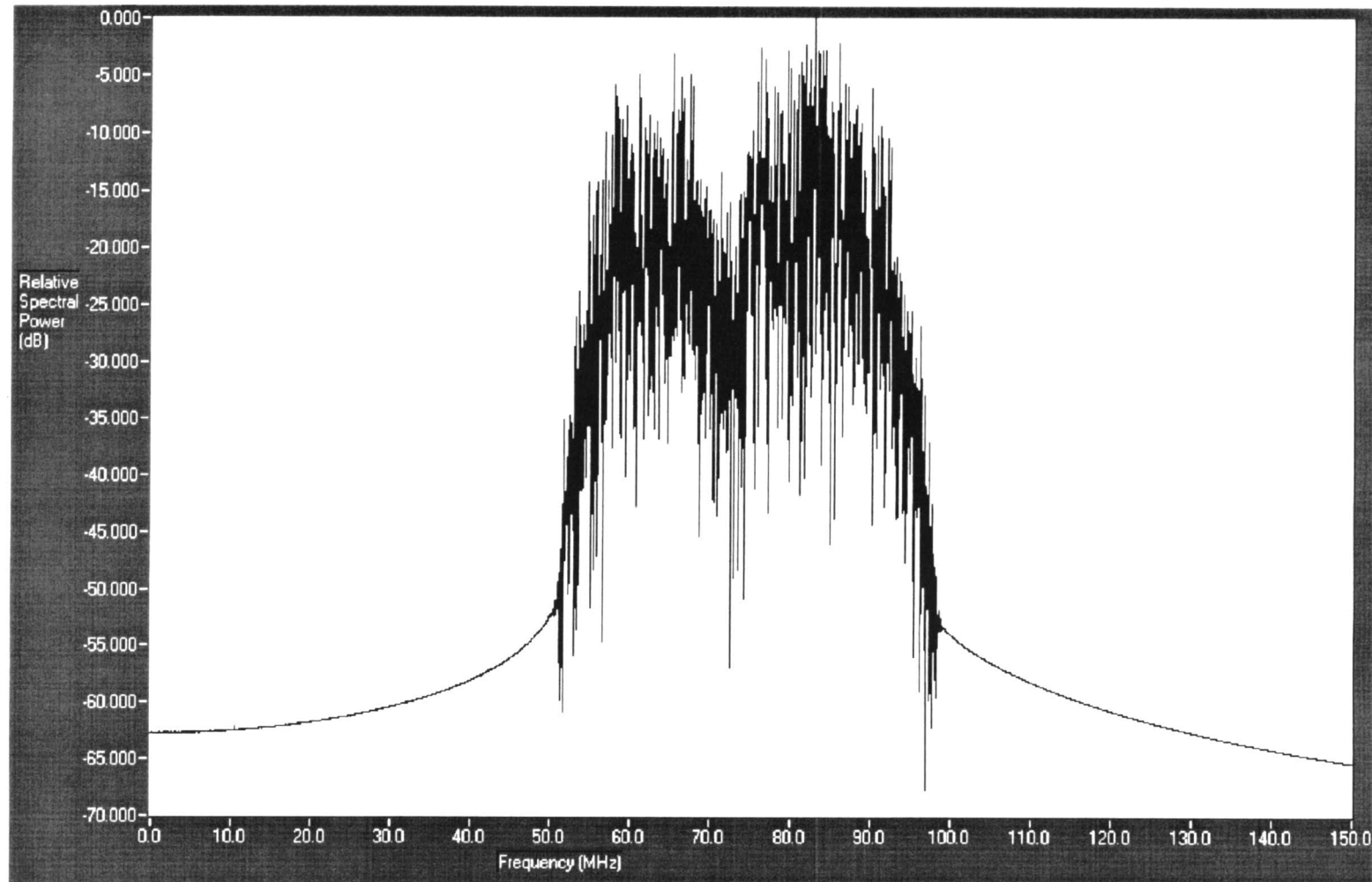
Los Alamos

Spectrum After Equalization
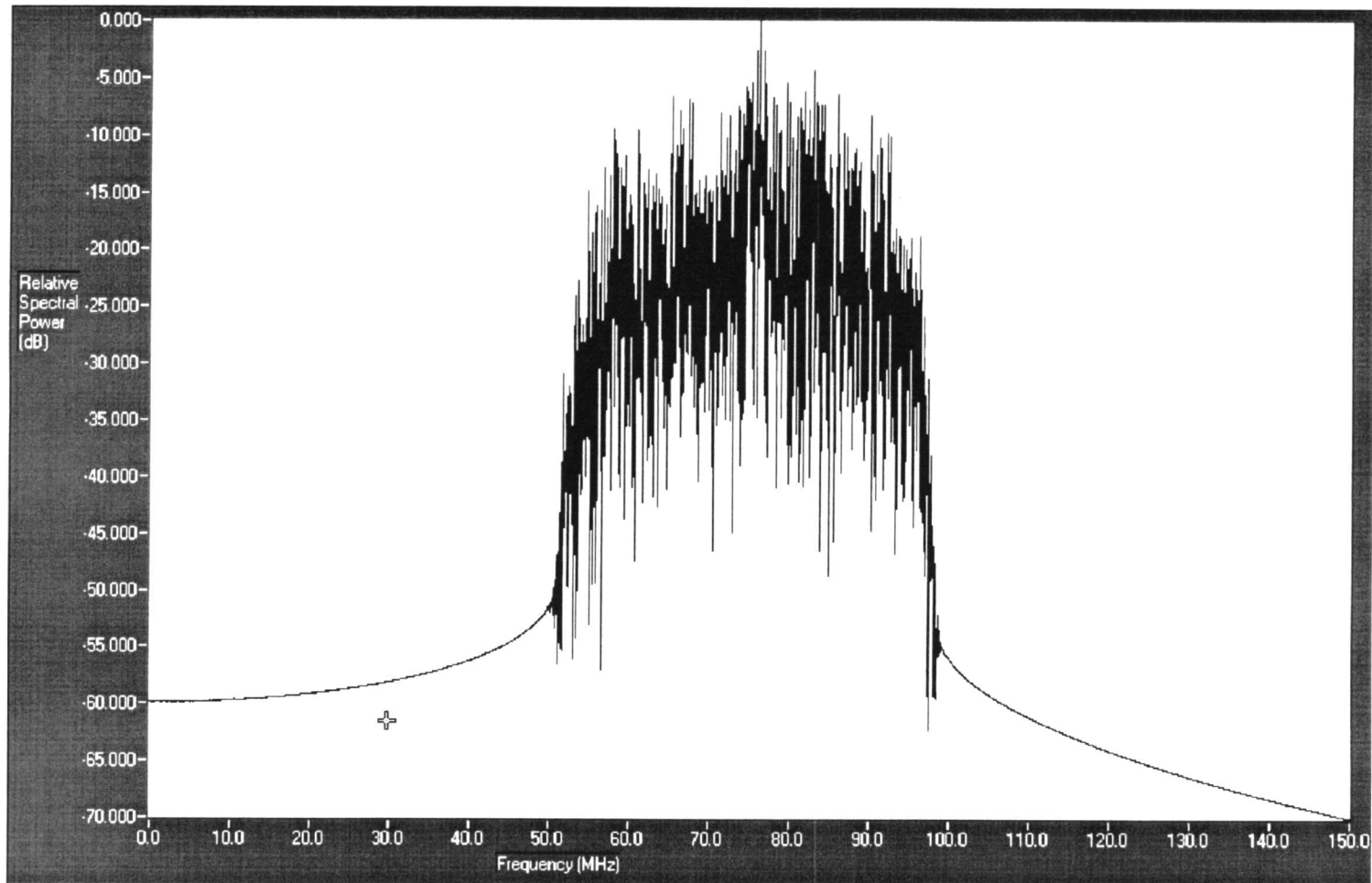
Los Alamos

Trigger Response Before Equalization

Trigger Response After Equalization
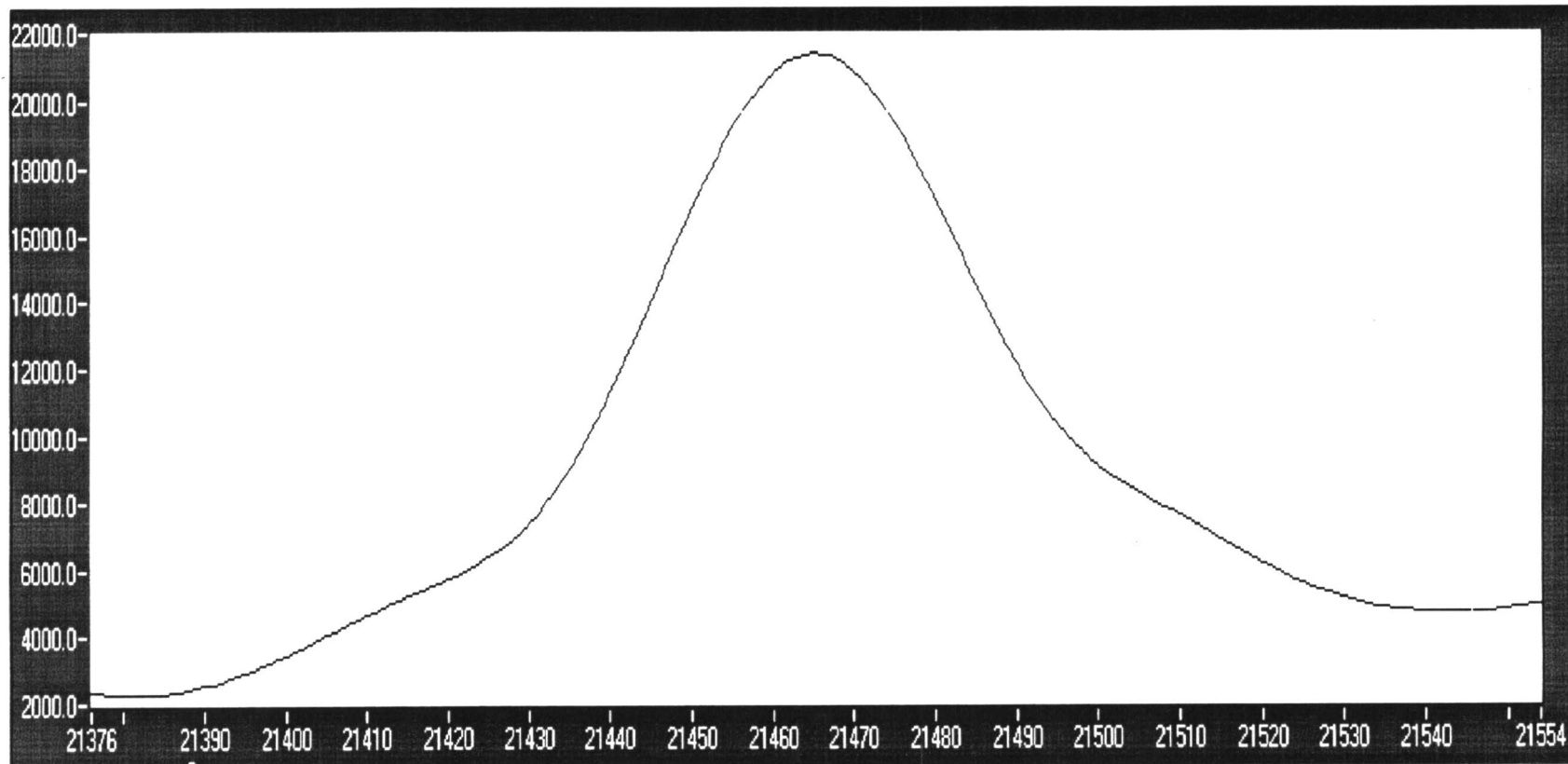
OTHER TESTS

Lighthouse to boat

Hurricane Point across bay to Lighthouse

Los Alamos

Equalization

In almost all cases multipath could be modeled as 2-ray

Successfully equalized by processing the received signal complex envelope, $s_k = I_k + jQ_k$
with a signle delay recursive filter,
$$\frac{1}{1+Ae^{jP}z^{-(D+1)}}$$

Where

A is the fractional amplitude of the 2nd multi-path signal relative to LOS signal

P is the relative angle,

D is the relative delay-1

In the rare cases where the reflected ray is larger than the incident ray
The open form of the above equation must be used

Additional iteration of single delay compensation resulted in further improvement
even though ideally parameters for all delays would be searched simultaneously

Honeywell

Los Alamos

Test Results
Aircraft to Boat

No significant problems

No significant satellite radio interference

Some flat fading detected

Occasional frequency dependent fading: from ship's mast

Honeywell

Los Alamos

Test Results
Aircraft to Lighthouse

Frequency Dependent Fading

Severe in-band satellite radio interference

Most data unusable due to interference

Honeywell

Los Alamos

HERT's Objective

To measure time of arrival with precisely located shock sensors in an "in flight high explosive system" and send that information by radio link to a receiving station.

HERT is a measurement system, not just some sensors

Cooperative efforts:
      Partner with Honeywell, Kansas City Plant
      Work closely with Sandia and
                    Lawrence Livermore National Labs

Extensively tested from 1995 to present:
      Non-Explosive Radio Frequency Ground Tests
      Explosive Ground Tests
          RF and Telemetry System
          Sensor Systems
    Flight Test Vandenberg to Kwajalein
          Telemetry System
          Flight Survival

Honeywell

Los Alamos

HERT Transmitter Implementation

100Mbit/sec raw data rate

40nS symbol period

Pulse mode of transmission

Fast switching linear amplifier

Embedded parity error encoding

FPGA controlled I-Q modulation

Honeywell

Los Alamos

HERT's General Features and Parameters

Time of arrival measurement for
     64 Channels, 10 ns resolution

Optical base sensor inputs

Simultaneous or time separated
measurements; 10ns to 160 • s

Small size   1.75 x 2.5 x 3.5 inches

Lightweight   1.25 lbs

Electrically efficient   5 watts

Operates in a BURST mode for
    efficient use of electrical
        power
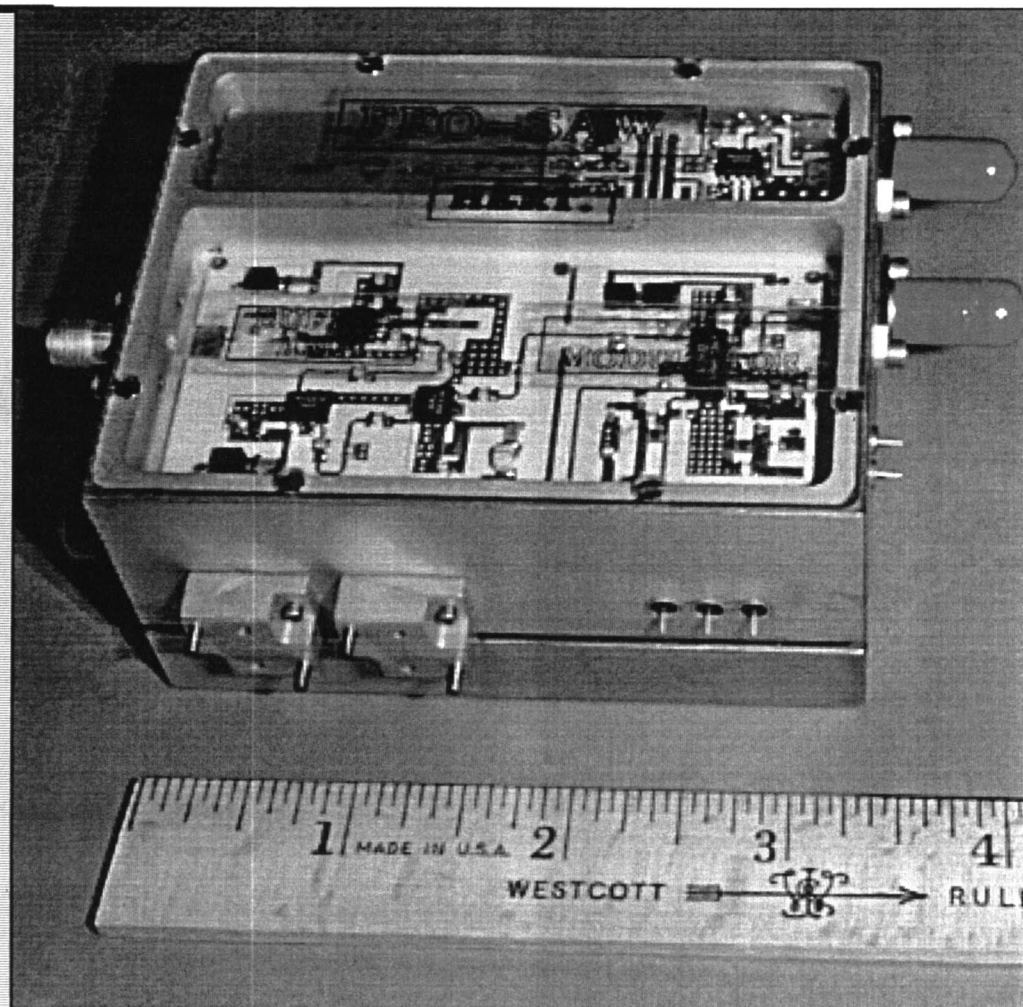
Honeywell

Los Alamos

HERT System Basic Block Diagram

Optical Interface, Program
Logic, and Quadrature Modulator

Transmission
Antenna

Fiber
Array
2 of 64

Optical to
Electrical
Converter
64 Ch.

Xylinx
Programable
Logic Array

"I"

"Q"

Quadrature
Modulator

Power
Amplifier

Frequency Source

Receiving
Antenna

RF Receiver

High Speed
Waveform
Digitizer

Laptop
Computer
with LabVIEW
Demodulation
Program

Trigger Detector

Honeywell

Los Alamos

HERT Systems

Sensors

Self-Check

Optical Detector

Logic

Radio Frequency (RF) and Modulation

Power Amplifier

Ground Station and Receiver
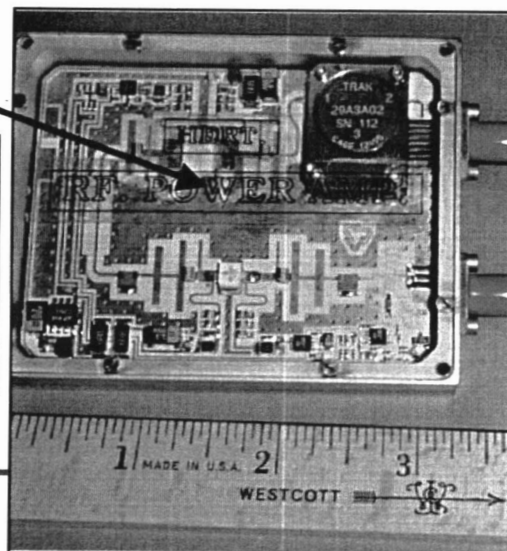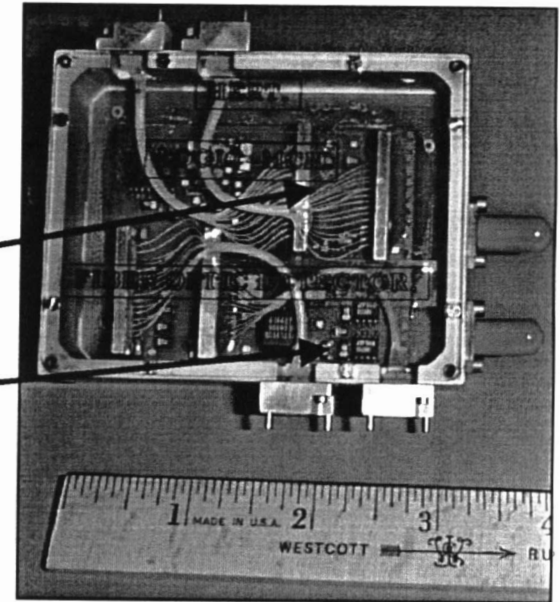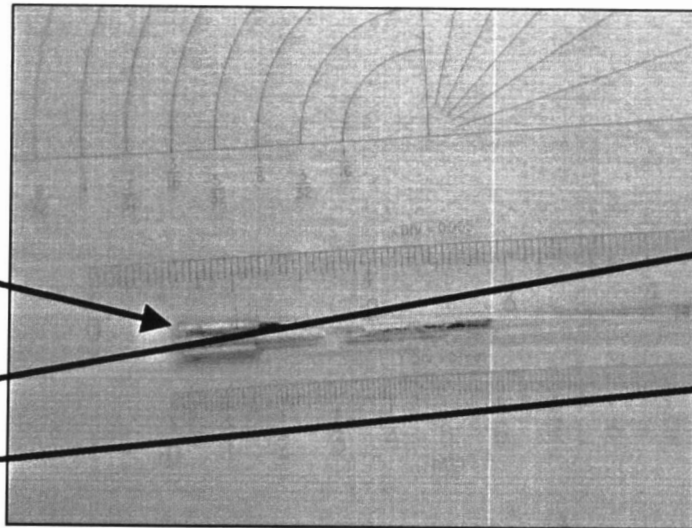
Honeywell

Los Alamos

Logic

Specifications and Features

100 MHz Xylinx PLA
Starts on arrival of first signal
10 ns detection of "Time
    of Arrival" for the
    64 optical inputs
Formats Channel #, Arrival time,
    and sequence of arrival
    for the 64 channels
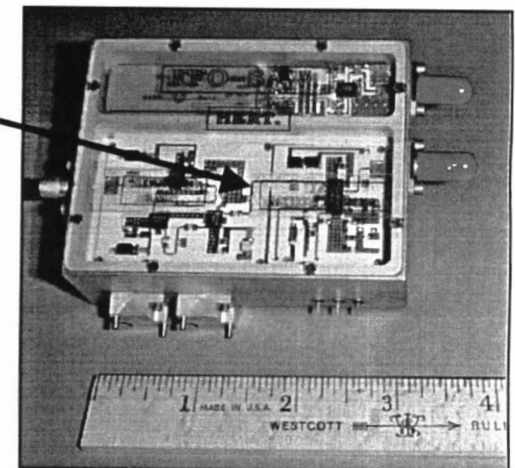Converts data into digital QAM-16
    format
Generates unique digital trigger
    word
Completes one cycle of transmission
    in about 16 • s

Multi-Chip-Module (MCM)
1 x 16 MT Fiber connector
1 x 16 Fiber Array
1 x 16 Optical to Electrical
    Convert Modules
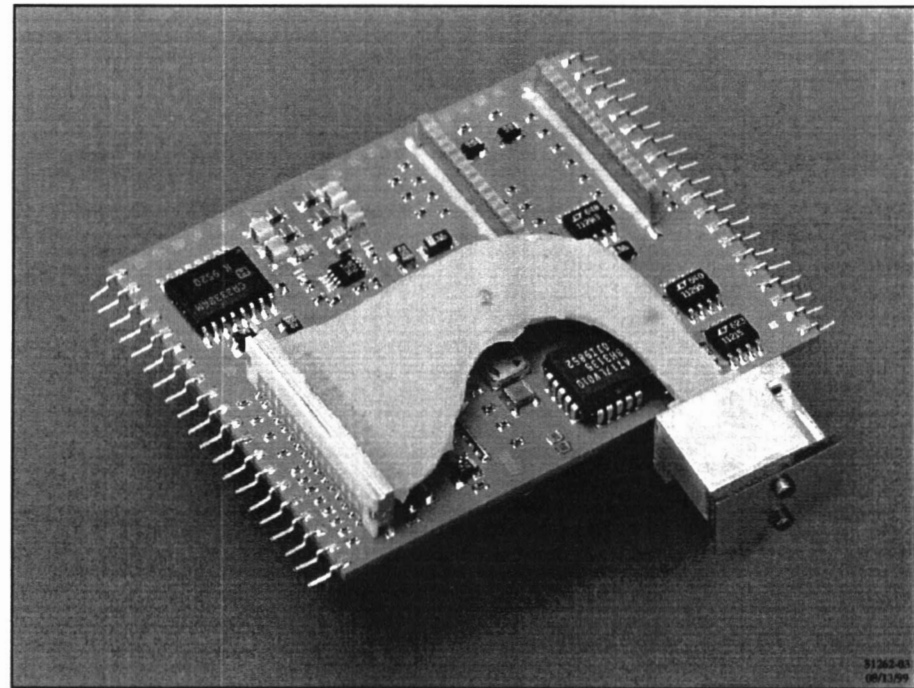
Honeywell

Los Alamos

Radio Frequency and Modulation

Adjustable Surface Acoustic Wave Oscillator (SAW) 2.2 to 2.4 GHz Flight Rugged

Quatrature Amplitude Modulator 16 State (QAM-16)

Buffer Amp 0.1 watt output

Honeywell

Los Alamos

Radio Frequency and Modulation

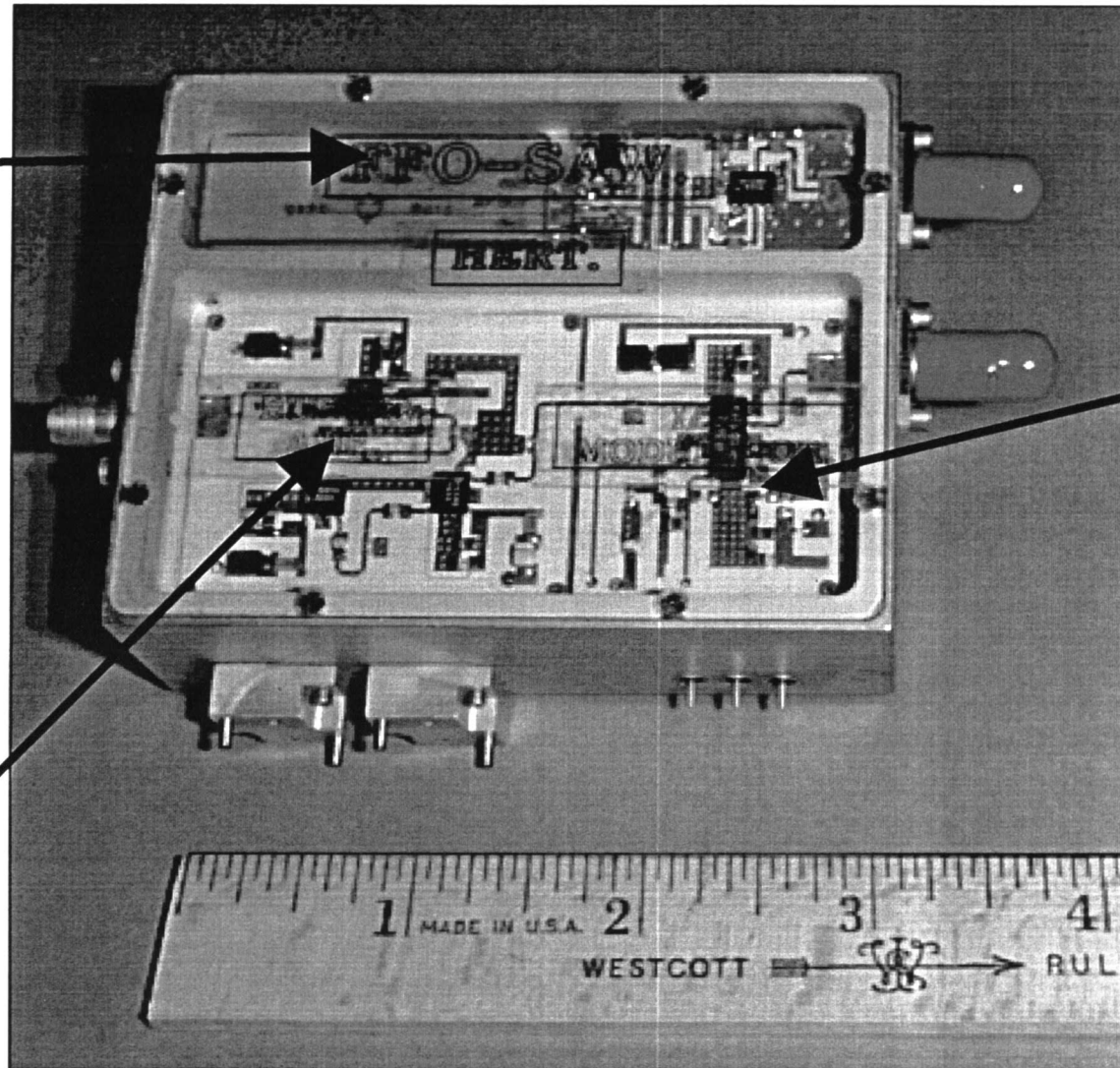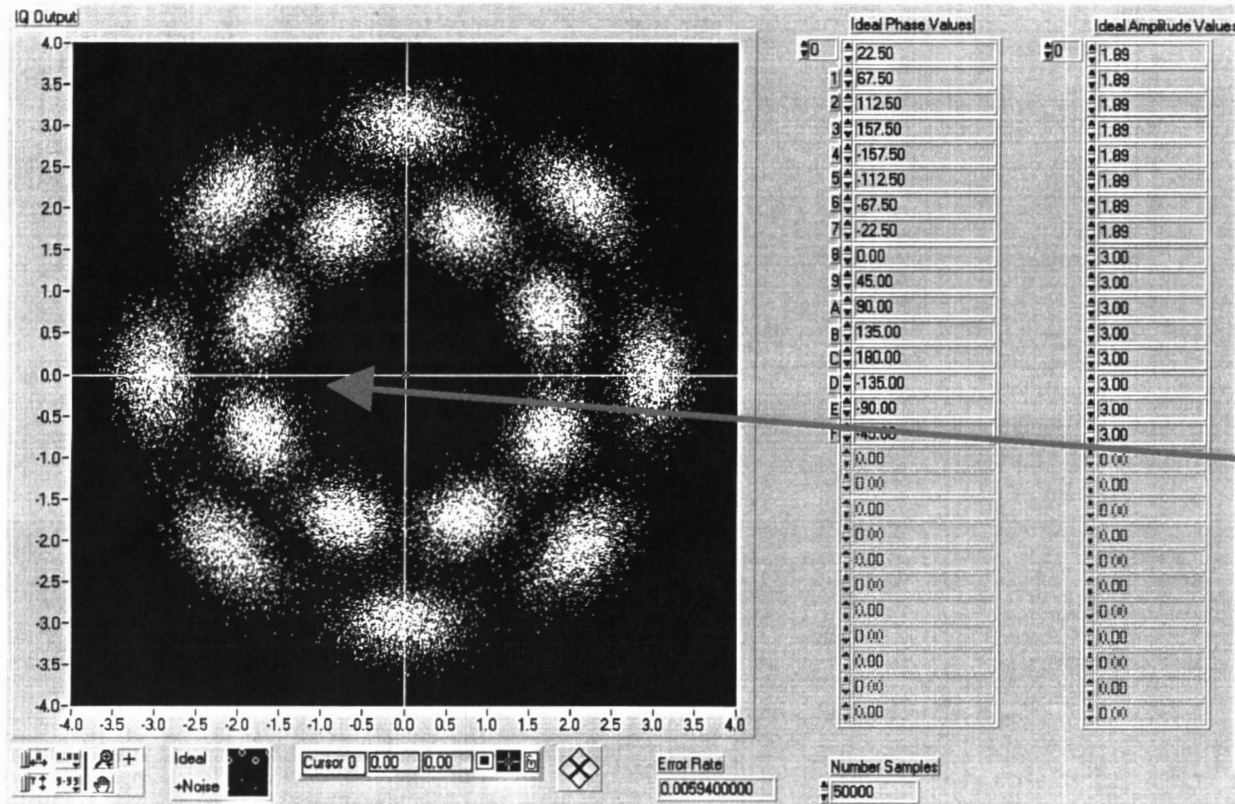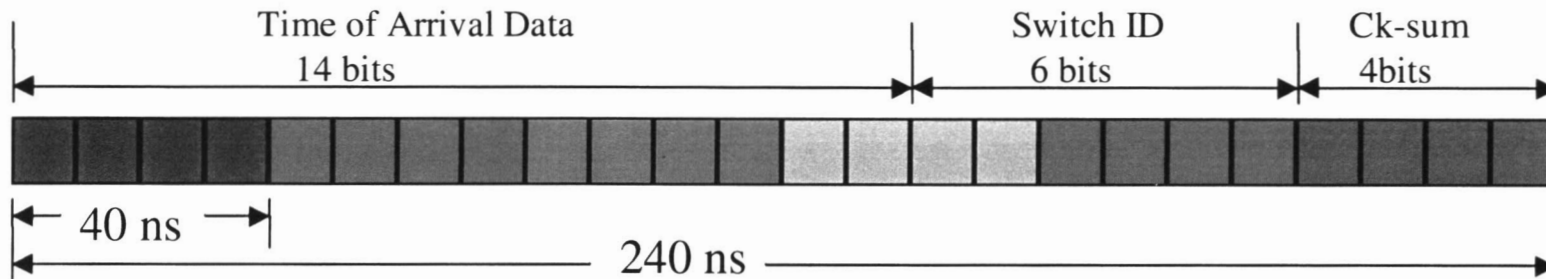| Time of Arrival Data 14 bits	Switch ID 6 bits	Ck-sum 4bits

|← 40 ns →|

|←————————————— 240 ns —————————————→|

IQ Output

Ideal Phase Values		Ideal Amplitude Values
0	22.50	0	1.89
1	67.50		1.89
2	112.50		1.89
3	157.50		1.89
4	-157.50		1.89
5	-112.50		1.89
6	-67.50		1.89
7	-22.50		1.89
8	0.00		3.00
9	45.00		3.00
A	90.00		3.00
B	135.00		3.00
C	180.00		3.00
D	-135.00		3.00
E	-90.00		3.00
F	-45.00		3.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00
	0.00		0.00

QAM-16 gives 4 to 1 data compression and reduces transmission time from 64 us to 16 us

Each spot represents a 4 bit hexadecimal word 1 = 1, 3 = 3, 10 = A, etc.

Data is represented by changes in Amplitude and Phase from one hex word to another hex word

| Ideal | +Noise |

| Cursor 0 | 0.00 | 0.00 |

Error Rate
0.0059400000

Number Samples
50000

Honeywell

Los Alamos

Novel Modulation Method

Differential-Phase / Absolute-Amplitude / Two-Level Polar / 16QAM

Advantages:

1. Less backoff needed than with rectangular QAM - 3dB works well

2. Allows coherent or non-coherent demodulation

3. Simple FPGA transmitter encoding algorithm

4. Spectrally efficient

5. High Data Rate

Honeywell

Los Alamos

Power Amplifier

Specifications and Features
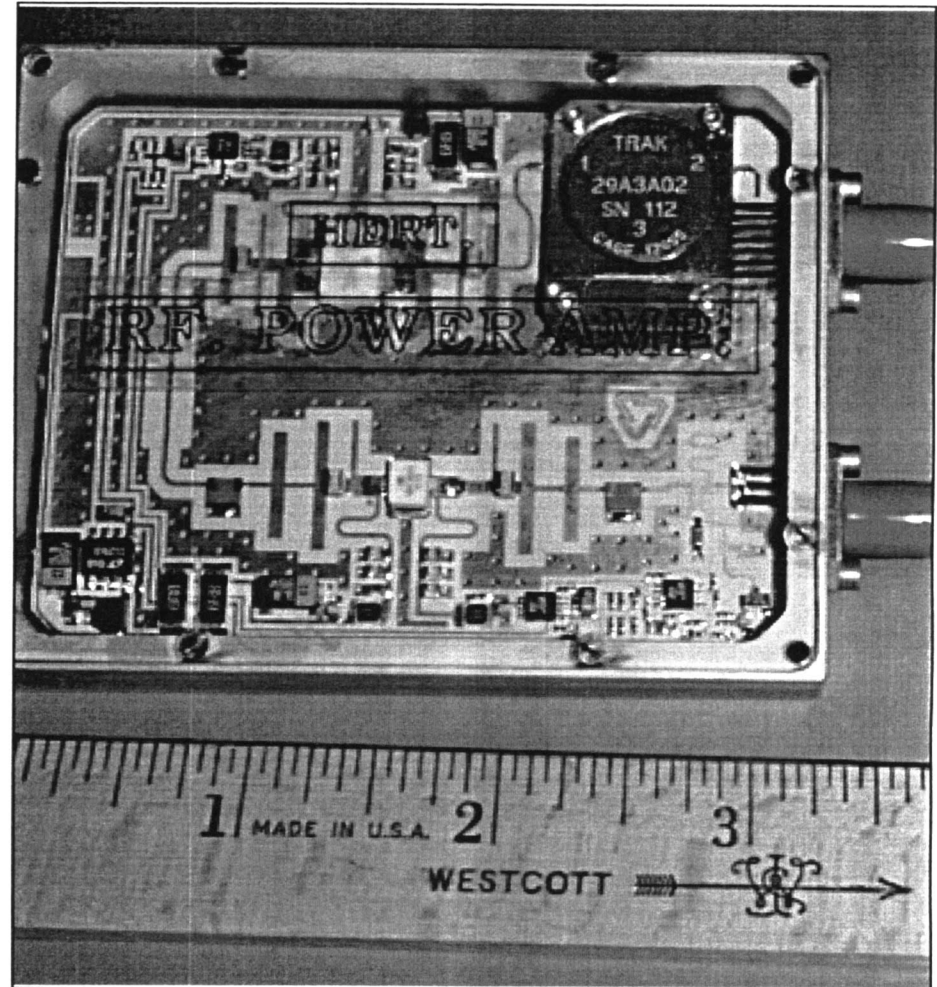Class A, Linear Operation

RF power out: 10 watts

Frequency: 2.2 to 2.4 GHz

Efficiency: About 20%

On only when the RF
burst from the Logic
and Modulator is Present

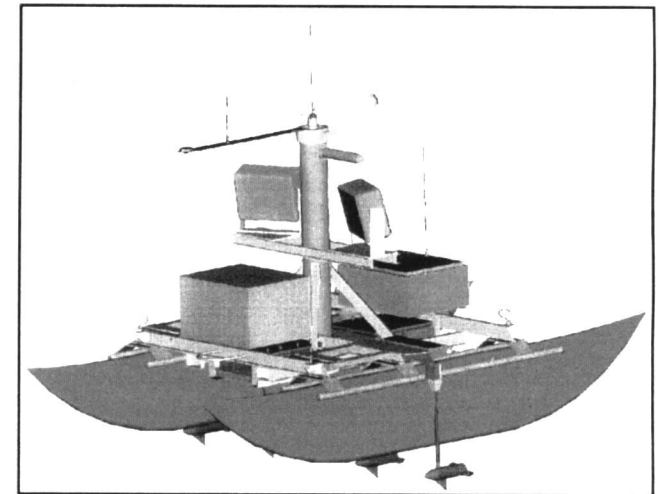Small in size, low weight

Configured with HERT or can
be moved

Los Alamos

Receiving Station Capabilities

Land-base with existing antennas and telemetry equipment

Sea-based on station keeping rafts

Air-based on telemetry receiving airplanes

Honeywell

Los Alamos

Conclusions

Ocean multi-path can usually be modeled as 2-ray and can be equalized with a single
delay recursive filter, or its non-recursive equivalent when main is weaker than the delayed ray

Although not ideal, additional improvement can be obtained by additional independent iterations
of 2-ray compensation.

Adequate optimization criteria for equalization are the "constellation spread" and "correlation of correlation".

HERT telemetry signals can usually be recovered even under most severe multipath conditions.

Los Alamos